

IN THE UNITED STATES PATENT AND TRADEMARK OFFICE

Applicant(s): Karthikeyan Ramasamy, Jie-Bing Yu, and Jun Li

Docket: 8343

Title: QUERY MONITOR PLAYBACK MECHANISM FOR POST-MORTEM PERFORMANCE ANALYSIS

11/24/99
USPTO

11/24/99
USPTO
JC 89/449085 PRO

CERTIFICATE OF MAILING UNDER 37 CFR 1.10

'Express Mail' mailing label number: EL307940434US

Date of Deposit: November 24, 1999

I hereby certify that this paper or fee is being deposited with the United States Postal Service 'Express Mail Post Office To Addressee' service under 37 CFR 1.10 and is addressed to the Assistant Commissioner for Patents, Washington, D.C. 20231.

By: *Isabell Ogata*
Name: Isabell Ogata

BOX PATENT APPLICATION

Assistant Commissioner for Patents
Washington, D.C. 20231

Sir:

We are transmitting herewith the attached:

- Transmittal sheet, in duplicate, containing Certificate Of Mailing Under 37 CFR 1.10.
- Utility Patent Application: Spec. 17 pgs; 35 claims; Abstract 1 pg(s).
The fee has been calculated as shown below in the "Claims as Filed" table.
- 11 sheets of Drawings
- An unsigned Declaration and Power of Attorney
- A charge to Deposit Account No. 14-0225 in the amount of \$1,108.00 to cover the Filing Fee
- Return postcard

CLAIMS AS FILED

Number of Claims Filed	In Excess of:	Number Extra	Rate	Fee
Basic Filing Fee				\$760.00
Total Claims				
35	20	15	x \$18.00	= \$270.00
Independent Claims				
4	3	1	x \$78.00	= \$78.00
MULTIPLE DEPENDENT CLAIM FEE				\$0.00
TOTAL FILING FEE				\$1,108.00

Please charge all fees to Deposit Account No. 14-0225 of NCR Corporation (the assignee of the present application).
A duplicate of this sheet is enclosed.

GATES & COOPER
Howard Hughes Center
6701 Center Drive West, Suite 1050
Los Angeles, CA 90045
(310) 641-8797

By: *Victor G. Cooper*
Name: Victor G. Cooper
Reg. No.: 39,641
Initials: VGC/io

QUERY MONITOR PLAYBACK MECHANISM
FOR POST-MORTEM PERFORMANCE ANALYSES

CROSS REFERENCE TO RELATED APPLICATIONS

5 This application is related to the following co-pending and commonly assigned patent application, which is incorporated by reference herein:

Application Serial No. --/---,---, entitled "METHOD AND APPARATUS FOR FETCHING ARRAY BASED OBJECTS BY DIRECT DELIVERY AND BATCHING" filed on same date herewith, by Zhe Wang, Biswadeep Nag, Jie-Bing
10 Yu, and Jignesh M. Patel, attorney's docket number 8342.

BACKGROUND OF THE INVENTION

1. Field of the Invention

15 The present invention relates to systems and methods for performing queries on data stored in a database, and in particular to a method and system for monitoring and reconstructing the execution of a database query.

2. Description of the Related Art

20 Large-scale integrated database management systems provide an efficient, consistent, and secure means for storing and retrieving vast amounts of data. This ability to manage massive amounts of information has become a virtual necessity in business today.

25 At the same time, wider varieties of data are available for storage and retrieval. In particular, multimedia applications are being introduced and deployed for a wide range of business and entertainment purposes, including multimedia storage, retrieval, and content analysis. Properly managed, multimedia information technology can be used to solve a wide variety of business problems.

30 Database management systems typically include a query monitoring utility that provides real-time monitoring of the execution of database queries. However, real-time query monitoring often does not allow field support engineers or database administrators (DBAs) to monitor and analyze all running queries, especially for

those which must be analyzed after the query is completed (post-mortem analysis). What is needed is a system and method that allows query execution to be recorded for playback after query execution. The present invention satisfies that need.

5

SUMMARY OF THE INVENTION

To address the requirements described above, the present invention discloses a method, apparatus, article of manufacture, and a memory structure for monitoring an executed query comprising at least one execution thread.

The method comprises the steps of executing the query; and while executing
10 the query, storing an execution trace record for each execution thread in at least one execution log file. The execution trace record comprises execution trace information including a thread ID and a time stamp for the execution thread. The execution trace information can be recalled from the execution log file and presented to a user after execution of the query to allow post mortem analysis of the query. The article of
15 manufacture comprises a program storage device tangibly embodying instructions for performing the method steps described above.

The apparatus comprises a data server for executing the execution thread and for storing an execution trace record for the executed execution thread, the execution trace record having execution trace information including a thread identifier and a
20 time stamp; a query coordinator, for storing an execution plan having a time stamp and for retrieving and synchronizing the execution trace record and the execution plan; and a client process for displaying the retrieved execution trace information to a user after execution of the query.

The foregoing playback mechanism can record all of the action in the
25 persistent files used by the execution threads of the database query, and allow a query monitor to play back the requested execution operations in a user-specified manner. The playback mechanism can also support pausing, fast-forward operations, fast backward operations, or display results and progress at any desired speed.

BRIEF DESCRIPTION OF THE DRAWINGS

Referring now to the drawings in which like reference numbers represent corresponding parts throughout:

5 FIG. 1 is a block diagram showing an exemplary environment for practicing the present invention;

FIG. 2 is a diagram showing one embodiment of the user front end of the exemplary hardware environment depicted in FIG. 1;

10 FIGs. 3A-3C present an example of an SQL query, an associated tree of rational operators, and an associated access plan;

FIG. 4 is a diagram depicting an overview of a class structure architecture that can be used with the present invention;

15 FIG. 5 is a diagram showing an operator class hierarchy for a relational optimizer;

FIG. 6 is a diagram showing an example of an operator tree corresponding to the query shown in FIG. 3A;

FIG. 7 is a diagram presenting an example of the operator tree depicted in FIG. 6 illustrating the associated tree descriptors;

15 FIG. 8 is a flow chart depicting exemplary operations used to practice one embodiment of the present invention;

20 FIG. 9 is a flow chart presenting illustrative process steps used to present the recalled execution trace information to the user;

FIG. 10 is a diagram showing an illustrative embodiment of a user interface used for post-mortem analysis; and

25 FIG. 11 is a diagram showing an exemplary computer system in which the present invention may be practiced.

RECORDED IN U.S. PATENT AND TRADEMARK OFFICE

DETAILED DESCRIPTION OF PREFERRED EMBODIMENTS

In the following description, reference is made to the accompanying drawings which form a part hereof, and which is shown, by way of illustration, several embodiments of the present invention. It is understood that other embodiments may 5 be utilized and structural changes may be made without departing from the scope of the present invention.

FIG. 1 is a diagram showing an exemplary environment in which the present invention may be practiced. The database system 100 uses a client-server architecture comprising a query scheduler 122 implemented in a query coordinator (QC) 104 and 10 one or more data servers (DS) 130A-130E (hereinafter referred to as data server(s) 130) storing data in one or more data storage devices 132A-132E (hereinafter referred to as data storage device(s) 132). The data servers 130 also perform portions of the execution plan in execution threads as determined by the query coordinator to execute the query. The query coordinator 104 and data servers 130 may be implemented in 15 separate machines, or may be implemented as separate or related processes in a single machine. The QC 104 and the DS 130 communicate via a communication infrastructure 134 which can automatically select the most efficient mechanism for the transport of data between the QC 104 and any one of the DS 130 elements. When a message is between processes or entities that do not share a common memory 20 system, a transport protocol such as transmission control protocol (TCP) or message passing interface (MPI) can be utilized to transfer the information. However, when the communication is between processors on a symmetric multiprocessing system (SMP), memory may be used as the transport vehicle.

Client processes 102, which can include applications or graphical user 25 interfaces (GUIs), can connect to the QC 104 to submit a query. After parsing and optimization, the QC 104 generates an execution plan for the query and transmits portions of that plan to the appropriate data servers 130A-130E for execution. Hence, the QC 104 controls the parallel execution of the query on the DS 130 processes.

Query results including result sets are collected by the QC 104 for delivery back to the client process 102.

The QC 104 and DS 130 processes can be implemented as multithreaded processes on top of a storage manager 128. The storage manager 128 provides storage volumes, files of untyped objects, B+ trees and R* trees. Objects can be arbitrarily large, up to the size of the storage volume. In one embodiment, allocation of storage space within a storage volume is performed in terms of fixed size extents. The associated I/O processes and the main storage manager 128 server process share the storage manager 128 buffer pool, which is kept in shared memory.

10 The database system 100 uses many basic parallelism mechanisms. Tables may be fully partitioned across all disks in the system 100 using round robin, hash, or spatial declustering. When a scan or selection query is executed, a separate thread is started for each fragment of each table.

15 In one embodiment, the database system 100 also uses a push model of parallelism to implement partitioned execution in which tuples are pushed from leaves of the operator tree upward. Every database system 100 operator (e.g. join, sort, and select) takes its input from an input stream and places its result tuples on an output stream. The streams themselves are C++ objects and can be specialized in the form of "file streams" and "network streams". File streams are used to read/write 20 tuples from/to disk. Network streams are used to move data between operators either through shared-memory or across a communications network via a transport protocol (e.g. TCP/IP or MPI). In addition to providing transparent communication between operators on the same or different processors, network streams also provide a flow-control mechanism that is used to regulate the execution rates of the different 25 operators in the pipeline. Network streams can be further specialized into split streams, which are used to demultiplex an output stream into multiple output streams based on a function being applied to each tuple. Split streams are one of the key mechanisms used to parallelize queries. Since all types of streams are derived from a base stream class, their interfaces are identical and the implementation of each

operator can be totally isolated from the type of stream it reads or writes. At runtime, the scheduler thread (running in the QC process 104), which is used to control the parallel execution of the query, instantiates the correct type of stream objects to connect the operators.

5 For the most part, the database system uses standard algorithms for each of the basic relational operators. Indexed selections are provided for both non-spatial and spatial selections. For join operations, the query optimizer 126 can choose from nested loops, indexed nested loops, and dynamic memory hybrid hash joins. The database system's query optimizer 126 considers replicating small outer tables when 10 an index exists on the join column of the inner table.

The database system uses a two-phase approach for the parallel execution of aggregate operations. For example, consider a query involving an average operator with a group by clause. During the first phase each participating thread processes its fragment of the input table producing a running sum and count for each group. 15 During the second phase a single processor (typically) combines the results from the first phase to produce an average value for each group.

Since standard SQL has a well defined set of aggregate operators, for each operator the functions that must be performed during the first and second phases are known when the system is being built and, hence, can be hard coded into the system. 20 However, in the case of an object-relational system that supports type extensibility, the set of aggregate operators is not known in advance as each new type added to the system may introduce new operators. Hence, a mechanism is provided for specifying the first and second phase function with the definition of each aggregate.

The query coordinator 104 also comprises a tuple manager 120, a catalog 25 manager 118, a query optimizer 126, a query scheduler 122, and a storage manager 128. The tuple manager 120 receives the tuples from the data servers 130, formats and processes the tuples, and passes them along to the client program or process 102. The catalog manager 118 manages metadata regarding the tables and types in the

database. The query optimizer generates an execution plan for queries received from the client process 102.

The client program 102 comprises a front end 108, which provides a graphical user interface that supports querying, browsing, and updating of database objects 5 through either its graphical or textual user interfaces. In either case, the front end transforms a query into an extended SQL syntax and transmits it to the query coordinator 104 for execution. After executing the query, the query coordinator 104 transmits the results back to the client program 102 in the form of a set of tuples which can be iterated over using a cursor mechanism. In one embodiment, all 10 communications between the front end 108 and the processes implemented in the query coordinator 104 are in the form of remote procedure calls 114A and 114B implemented over a Transmission Control Protocol/Internet Protocol (TCP/IP). The client process 102 also comprises a tuple cache 106 for retaining tuples received from the query coordinator 104. ADTs 116A and 116B can be stored and/or processed in 15 either the query coordinator 104 or the client process 102.

The client front end 108 permits the display of objects with spatial attributes on a 2-D map. For objects with multiple spatial attributes, one of the spatial attributes can be used to specify the position of the object on the screen. The spatial ADTs currently supported include points, closed polygons, polylines, and raster images.

20 The client front end 108 can also present a layered display of overlapping spatial attributes from different queries or tables. For example, one can display city objects that satisfy a certain predicate (e.g. population > 300K) in one layer on top of a second layer of country objects.

25 The client front end 108 also allows the user to query through a graphical interface; implicitly issuing spatial queries by zooming, clicking, or sketching a rubber-banded box on the 2-D map. The graphical capabilities of the client can be implemented using toolkits such as Tk/X11. Further, the user can query by explicitly composing ad-hoc queries in the database system's 100 extended SQL syntax.

The user can use the client front end 108 to browse the objects from a table.

In this mode, attributes are displayed as ASCII strings. The front end 108 can also be used to update database objects. Object(s) to be updated can be selected either by pointing-and-clicking on the 2-D map or by selecting via the textual browser.

5 Finally, the client front end 108 can also be used to perform general catalog operations including browsing, creating new databases, defining new tables, creating indices on attributes, and bulk loading data into tables from external files.

10 The database system 100 also advantageously uses a second communication path 140 to transmit selected data such as master object data and large objects to the client 102, as described further below. This data is received by the direct data transfer module 142 in the client 102.

15 FIG. 2 is a diagram showing one embodiment of the user front end of the exemplary environment depicted in FIG. 1. The client front end 108 comprises a map view 202, layer manager 204, browser 206 and a query composer 208. The map view 202 is responsible for displaying and manipulating objects contained in one or more layers. The current position of the cursor is continuously displayed in a sub-window in units of the map projection system. Users can point and click on displayed objects to view their non-spatial attributes. The layer manager 204 is responsible for adding, deleting, hiding, and reordering layers displayed by the map view 202. Each layer 20 corresponds to a table of objects produced by executing some query. The extent browser 206 allows a user to view any database table and adjust the way it should be displayed by the map view 202. The selected table becomes a new layer with its spatial attributes displayable via the map view 202.

20 The query composer 208 allows a user to compose a SQL query using a simple text editor. The RPC 114 is the interface to the query coordinator 104. It ships SQL queries to the query coordinator 104 for execution and retrieves result tuples into the cache 210. The cache 210 comprises a master data cache 210A, a metadata cache 210B and an object cache 210C. The object cache 210C caches the result of a query in formats understood by the map view 202. The metadata cache 210 stores the

catalog information of the currently open database. The master data cache 210A stores retrieved master data as described further below. In one embodiment, the object cache 210C also caches the objects downloaded from the data servers 130.

FIG. 2 also shows the second communication path 140 from the data server 130 to the user front end 108 via the direct data transfer module 142.

Array-based abstract data types can be used as basis for a number of useful data types, including BLOBs, CLOBs, video, audio, text, image, maps and other large objects. Array-based ADT use an external out-of-line storage for very large objects.

Queries can be logically represented as an operator tree. An operator tree is a tree in which each node represents a logical query algebra operator being applied to its inputs.

FIGs. 3A, 3B, and 3C present an example SQL query, an associated tree of rational operators, and an associated access plan. A given query can be represented by one or more equivalent operator trees.

One or more physical execution algorithms can be used in a database for implementing a given query algebra operator. For instance, the join operator can be implemented using nested-loops or sort-merge algorithms. Replacing the operators in an operator tree by the algorithms used to implement them gives rise to a "tree of algorithms" known as an access plan or an execution plan. FIG. 3C shows one possible access plan corresponding to the operator tree in FIG. 3B. Each operator tree will, in general, have a number of corresponding access plans.

During the query optimization process, a query optimizer 126 must generate various operator trees that represent the input query (or parts of it), generate various access plans corresponding to each operator tree, and compute/estimate various properties of the operator trees and access plans (for example, cardinality of the output relation, estimated execution cost, etc.). This is implemented in OPT++ in a query-algebra-independent manner.

FIG. 4 is a diagram depicting an overview of the OPT++ architecture. A key feature of OPT++ is that a few abstract classes and their virtual methods are defined a

priori and the search strategy is written entirely in terms of these classes. OPT++ uses abstract classes to represent operator trees and access plans and compute their properties. OPT++ uses abstract classes to generate and manipulate different operator trees and their corresponding access plans.

5 The foregoing abstract classes include the OPERATOR and ALGORITHM abstract classes. These classes are used to represent operator trees and access plans, and for computing their properties.

10 FIG. 5 is a diagram showing the operator class hierarchy for a relational optimizer such as the query optimizer 126. In FIG. 5, classes are represented by oval shapes, and an arrow between classes indicates an inheritance relationship. As shown in FIG. 5, operators, inherit characteristics from, for example, database relations 504, select class 508, and join class 506.

15 The abstract OPERATOR class represents operators in the query algebra. From the OPERATOR class an optimizer implementor (OI) such as the query optimizer 126 is expected to derive one class for each operator in the actual query algebra. An instance of one of these derived operator classes represents the application of the corresponding query language operator. As an example, the classes that an OI might derive from the OPERATOR class to implement a simple SQL optimizer are shown in FIG. 3. The SELECT and JOIN classes (508 and 506, respectively) represent the relational select and the relational join operators respectively. The DB-RELATION operator 504 is explained below. In this SQL optimizer, an instance of the SELECT operator 508 represents an application of the relational select operator to one input relation, and an instance of the JOIN operator 506 represents an application of the relational join operator to two input relations.

20 25 The inputs of an operator can either be database entities (for example, relations for a relational database) that already exist in the database, or they can be the result of the application of other operators. An operator tree can thus be represented as a tree of instances of the operator class (more accurately, an instance of a class derived from the abstract OPERATOR class).

Dummy operators serve as leaf nodes of the operator tree, representing database entities that already exist in the database. For example, the relations in the “from” clause of an SQL query are represented by the dummy DB-RELATION operator in the illustrations that follow.

5 FIG. 6 is a diagram showing an example of an operator tree corresponding to the query shown in FIG 3A. The two instances of the DB-RELATION class (instance 608 and instance 606) represent the two relations in the from clause of the query - “Emp” and “Dept.” The instance of the SELECT class 604 represents a selection on the “Emp” relation, and the instance of the JOIN class 602 represents the “Dept” 10 relation being joined to the result of the selection.

FIG. 7 is a diagram presenting an example of the operator tree depicted in FIG. 6 illustrating its associated tree descriptors 702-708. During the course of optimization, the optimizer needs to compute and keep track of the properties of the resultant output of an operator tree. For example, a simple relational optimizer needs 15 to estimate properties such as the cardinality, or the size of the relation resulting from the execution of an operator tree. Since such information depends upon the query algebra, OPT++ has to rely on the OI to provide these properties. To do this, the OI is expected to define a TREEDESCRIPTOR class that stores information about an operator tree. The information stored could be logical algebraic properties (e.g., set of 20 relations already joined in, predicates applied), estimated properties (e.g., number of tuples in output) or any other information of interest to the OI.

In FIGs. 3-7, classes are depicted as ovals and instances are depicted as boxes. Thus class hierarchies are depicted using ovals, while operator trees and access plans will be drawn using boxes. Every operator instance contains a pointer to an instance 25 of the TREEDESCRIPTOR class, that stores information about the operator tree rooted at that operator instance. FIG. 7 reproduces the operator tree of FIG. 6 showing the TREEDESCRIPTOR instances associated with each operator instance. In this example, each TREEDESCRIPTOR instance lists the names of the relations that have been joined in and the predicates applied.

With the TREEDESCRIPTOR class the OI must provide an IsEquivalent method that determines whether two TREEDESCRIPTOR instances are equivalent. Two TREEDESCRIPTOR instances should be equivalent if the corresponding operator trees are algebraically equivalent. The TREEDESCRIPTOR also has an 5 IsCompleteQuery method that determines whether the corresponding operator tree represents the whole query or just a sub-computation.

The OPERATOR class includes a virtual method called DERIVETREEDESCRIPTOR. This method is invoked on an operator instance to construct the TREEDESCRIPTOR object for the operator tree rooted at that operator 10 instance, given the TREEDESCRIPTOR instances of its input operators.

The OPERATOR class has another virtual method called CANBEAPPLIED that determines whether that operator can be legally applied to given inputs according to the rules of the query algebra.

Given an operator tree, the search strategy can compute the 15 TREEDESCRIPTOR for it by invoking the DERIVETREEDESCRIPTOR method on each of the operator instances in the tree. Note that the search strategy just invokes the methods on the abstract OPERATOR class and does not require any information about the actual class of each instance. Through runtime binding, the proper DERIVETREEDESCRIPTOR method is invoked and the correct 20 TREEDESCRIPTOR computed. Thus the search strategy (which is implemented in terms of the abstract OPERATOR class) can compute the correct TREEDESCRIPTORS for an operator tree even though it has no knowledge of the actual operators in the query algebra. The IsCompleteQuery, IsEquivalent and the CANBEAPPLIED methods can be used to analyze the generated operator trees.

25 FIG. 8 is a flow chart depicting exemplary operations used to practice one embodiment of the present invention. When the query is executed, 802, query execution trace information for each execution thread is saved to an external log file, as shown in block 804. The execution trace information may also be sent directly to the query monitor as well, if directed by a suitable user command. In one

embodiment, execution trace information is saved as a default operation, without user intervention. In an alternative embodiment, the information is not stored unless the user directs as such.

In one embodiment the query coordinator 122 and each data server 130 write
5 the query execution trace information to a single log file, where it can be
reconstructed when desired. In one embodiment, the query coordinator 104 and each
data server 130 writes query execution trace information to a separate log file, and the
information is later reconstructed when post-mortem analysis is desired. The
execution trace information from the query coordinator 104 includes an execution
10 plan in terms of the operator trees described herein, operator dispatch information,
including operating nodes and device identifications, output data flow destinations,
and the start and stop times for the operators. The execution trace information from
the data servers includes the session ID, the query ID, and the following for each
operator: the operator ID, each operator thread's start time stamp, each operator
15 thread's processing tuple count, and each operator thread's finish time. If the operator
thread's processing tuple count is excessively large (as may be experienced with long
running transactions) it can be flushed out periodically.

Each execution trace record includes identity information including the thread
ID and time stamp information. The time stamps may reference a clock time, or may
20 be logical. The time stamps are loosely synchronized by periodic messages from the
query coordinator 104. The relationship between logical time stamps to real time
stamps can also be loosely established by the query coordinator 104 node by periodic
trace entries that include a real time stamp and a logical time stamp. In cases where
the execution trace records are written to different files, each file is uniquely names to
25 reflect its identity.

The query execution trace file can be split into multiple partitions based upon
the mount of trace information and the availability of local disk space for storage.
The partitions can be reused if the amount of trace information exceeds the monitor
window. Or the partitions can be flushed to permanent archiving storage devices like

tape or hard disks for later retrieval of historical data. In this case time stamp information is encoded into the file name to facilitate retrieval and organization. Since the execution trace information is highly structured, schema can be defined in the information and loaded into an external data warehouse for further analysis

5 purposes.

Returning to FIG. 8, after the query has completed execution 806, the execution trace information is recalled from the execution log file(s), as shown in block 808. Where the execution trace information is stored in multiple files, a query monitor implemented in either the client process 102 (preferably in the user front end 108 or in the query coordinator 104) gathers information by reading the execution trace information directly from the files saved by the query coordinator. These files can be saved in the query coordinator 104 or in the data storage devices 132 by the data server 130.

FIG. 9 is a flow chart presenting illustrative process steps used to present the 15 recalled execution trace information to the user. First, a presentation command is accepted. The presentation command may include, for example, any combination video cassette recorder (VCR) type functions, including a play command, a stop command, a pause command, a reverse play command, a fast play command, and a fast reverse play command. The retrieved execution trace information is then 20 arranged according to the thread ID, the time stamp, and the selected playback command.

FIG. 10 is a diagram showing an illustrative embodiment of a user interface used for post-mortem analysis. Analysis results are presented in a window 1002, having a series of presentation command tools 1004, including a fast reverse play 25 command tool 1004A, a reverse play command tool 1004B, a pause command tool 1004C, a stop command tool 1004D, a play command tool 1004E, a fast play command tool 1004F, and a recording command tool 1004G. The user can also fast forward, reverse, pause or stop playback using the scrollable bar 1006. Multiple correlated windows 1008-1012 show concurrent activities performed by the query

coordinator 122 and the data server(s) 130A-130E. The user can select which data servers 130 present execution trace information, using drop-down menu elements 1024, and can control the size and presentation of the correlated windows 1008-1014. In one embodiment, the execution trace information is presented in the form of 5 operator trees 1016. Other information, including time stamps can be provided as well.

FIG. 11 illustrates an exemplary computer system 1100 that could be used to implement the client process 102, query coordinator 104, or data server 130 of the present invention. The computer 1102 comprises a processor 1104 and a memory, 10 such as random access memory (RAM) 1106. The computer 1102 is operatively coupled to a display 1122, which presents images such as windows to the user on a graphical user interface 1118B. The computer 1102 may be coupled to other devices, such as a keyboard 1114, a mouse device 1116, a printer, etc. Of course, those skilled in the art will recognize that any combination of the above components, or any 15 number of different components, peripherals, and other devices, may be used with the computer 1102.

Generally, the computer 1102 operates under control of an operating system 1108 stored in the memory 1106, and interfaces with the user to accept inputs and commands and to present results through a graphical user interface (GUI) module 20 1118A. Although the GUI module 1118A is depicted as a separate module, the instructions performing the GUI functions can be resident or distributed in the operating system 1108, the computer program 1110, or implemented with special purpose memory and processors. The computer 1102 also implements a compiler 1112 which allows an application program 1110 written in a programming language 25 such as COBOL, C++, FORTRAN, or other language to be translated into processor 1104 readable code. After completion, the application 1110 accesses and manipulates data stored in the memory 1106 of the computer 1102 using the relationships and logic that was generated using the compiler 1112. The computer 1102 also optionally

comprises an external communication device such as a modem, satellite link, Ethernet card, or other device for communicating with other computers.

In one embodiment, instructions implementing the operating system 108, the computer program 1110, and the compiler 1112 are tangibly embodied in a computer-readable medium, e.g., data storage device 1120, which could include one or more fixed or removable data storage devices, such as a zip drive, floppy disc drive 1124, hard drive, CD-ROM drive, tape drive, etc. Further, the operating system 1108 and the computer program 1110 are comprised of instructions which, when read and executed by the computer 1102, cause the computer 1102 to perform the steps

5 necessary to implement and/or use the present invention. Computer program 1110 and/or operating instructions may also be tangibly embodied in memory 1106 and/or data communications devices, thereby making a computer program product or article of manufacture according to the invention. As such, the terms "article of manufacture" and "computer program product," or "program storage device" as used

10 herein are intended to encompass a computer program accessible from any computer readable device or media.

15

Those skilled in the art will recognize many modifications may be made to this configuration without departing from the scope of the present invention. For example, those skilled in the art will recognize that any combination of the above

20 components, or any number of different components, peripherals, and other devices, may be used with the present invention.

Conclusion

This concludes the description of the preferred embodiments of the present

25 invention. In summary, the present invention describes a method, apparatus, and article of manufacture for monitoring an executed query.

The method comprises the steps of executing the query; and while executing the query, storing an execution trace record for each execution thread in at least one execution log file. The execution trace record comprises execution trace information

including a thread ID and a time stamp for the execution thread. The execution trace information can be recalled from the execution log file and presented to a user after execution of the query to allow post mortem analysis of the query. The article of manufacture comprises a program storage device tangibly embodying instructions for
5 performing the method steps described above.

The apparatus comprises a data server for executing the execution thread and for storing an execution trace record for the executed execution thread, the execution trace record having execution trace information including a thread identifier and a time stamp; a query coordinator, for storing an execution plan having a time stamp
10 and for retrieving and synchronizing the execution trace record and the execution plan; and a client process for displaying the retrieved execution trace information to a user after execution of the query.

The foregoing description of the preferred embodiment of the invention has been presented for the purposes of illustration and description. It is not intended to be
15 exhaustive or to limit the invention to the precise form disclosed. Many modifications and variations are possible in light of the above teaching. It is intended that the scope of the invention be limited not by this detailed description, but rather by the claims appended hereto. The above specification, examples and data provide a complete description of the manufacture and use of the composition of the invention.
20 Since many embodiments of the invention can be made without departing from the spirit and scope of the invention, the invention resides in the claims hereinafter appended.

WHAT IS CLAIMED IS:

1. A method of monitoring an execution of a query, wherein the query execution comprises at least one execution thread, the method comprising the steps of:
 - 5 storing an execution trace record for each execution thread, the execution trace record having execution trace information including a thread identifier (ID) and a time stamp;
 - retrieving the execution trace information; and
 - presenting the retrieved execution trace information to a user after execution
- 10 of the query.
2. The method of claim 1, further comprising the step of executing the query, and wherein the step of storing an execution trace record for each execution thread is performed while executing the query.
- 15
3. The method of claim 1, wherein the query execution comprises a plurality of execution threads, and the step of presenting the retrieved execution trace information to the user comprises the step of synchronizing the execution trace records according to the thread ID and the time stamp.
- 20
4. The method of claim 1, wherein the time stamp is an absolute time stamp.
5. The method of claim 1, wherein the time stamp is a logical time stamp.
- 25
6. The method of claim 1, wherein the step of storing an execution trace record for each execution thread in at least one execution log file comprises the step of splitting the execution log file into a plurality of partitions.

7. The method of claim 6, wherein the execution log file is split into the plurality of partitions based upon an amount of execution trace information and an amount of storage space.

5

8. The method of claim 6, further comprising the steps of reusing the partitions when the execution log file exceeds a partition size.

9. The method of claim 1, wherein the step of presenting the retrieved 10 execution trace information to a user comprises the steps of:
accepting a presentation command; and
arranging the retrieved execution trace records according to the thread ID, the time stamp and the playback command.

15 10. The method of claim 9, wherein the presentation command is selected from the group comprising a play command, a stop command, a reverse play command, a fast play command, and a fast reverse play command.

11. An apparatus for monitoring an execution of a query, wherein the 20 query execution comprises at least one execution thread, comprising:
means for storing an execution trace record for each execution thread, the execution trace record having execution trace information including a thread identifier (ID) and a time stamp;
means for retrieving the execution trace information; and
25 means for presenting the retrieved execution trace information to a user after execution of the query.

12. The apparatus of claim 11, further comprising means for executing the query, and wherein means for storing an execution trace record for each execution thread is performed while executing the query.

5 13. The apparatus of claim 11, wherein the query execution comprises a plurality of execution threads, and the means for presenting the retrieved execution trace information to the user comprises means for synchronizing the execution trace records according to the thread ID and the time stamp.

10 14. The apparatus of claim 11, wherein the time stamp is an absolute time stamp.

15 15. The apparatus of claim 11, wherein the time stamp is a logical time stamp.

15 16. The apparatus of claim 11, wherein the means for storing an execution trace record for each execution thread in at least one execution log file comprises means for splitting the execution log file into a plurality of partitions.

20 17. The apparatus of claim 16, wherein the execution log file is split into the plurality of partitions based upon an amount of execution trace information and an amount of storage space.

25 18. The apparatus of claim 16, further comprising means for reusing the partitions when the execution log file exceeds a partition size.

19. The apparatus of claim 11, wherein the means for presenting the retrieved execution trace information to a user comprises:

means for accepting a presentation command; and

means for arranging the retrieved execution trace records according to the

5 thread ID, the time stamp and the playback command.

20. The apparatus of claim 19, wherein the presentation command is selected from the group comprising a play command, a stop command, a reverse play command, a fast play command, and a fast reverse play command.

10

21. A program storage device, readable by a computer, tangibly embodying at least one program of instructions executable by the computer to perform method steps of monitoring an execution of a query, wherein the query execution comprises at least one execution thread, the method steps comprising the steps of:

15 storing an execution trace record for each execution thread, the execution trace record having execution trace information including a thread identifier (ID) and a time stamp;

retrieving the execution trace information; and

20 presenting the retrieved execution trace information to a user after execution of the query.

22. The program storage device of claim 21, wherein the method steps further comprise the step of executing the query, and wherein the method step of storing an execution trace record for each execution thread is performed while

25 executing the query.

23. The program storage device of claim 21, wherein the query execution comprises a plurality of execution threads, and the method step of presenting the retrieved execution trace information to the user comprises the method step of synchronizing the execution trace records according to the thread ID and the time
5 stamp.

24. The program storage device of claim 21, wherein the time stamp is an absolute time stamp.

10 25. The program storage device of claim 21, wherein the time stamp is a logical time stamp.

15 26. The program storage device of claim 21, wherein the step of storing an execution trace record for each execution thread in at least one execution log file comprises the step of splitting the execution log file into a plurality of partitions.

20 27. The program storage device of claim 26, wherein the execution log file is split into the plurality of partitions based upon an amount of execution trace information and an amount of storage space.

28. The program storage device of claim 26, further comprising the steps of reusing the partitions when the execution log file exceeds a partition size.

25 29. The program storage device of claim 21, wherein the step of presenting the retrieved execution trace information to a user comprises the steps of:
accepting a presentation command; and
arranging the retrieved execution trace records according to the thread ID, the time stamp and the playback command.

30. The program storage device of claim 29, wherein the presentation command is selected from the group comprising a play command, a stop command, a reverse play command, a fast play command, and a fast reverse play command.

5 31. An apparatus for monitoring an execution of a query, wherein the query execution comprises at least one execution thread, comprising:

a data server for executing the execution thread and for storing an execution trace record for the executed execution thread, the execution trace record having execution trace information including a thread identifier (ID) and a time stamp;

10 a query coordinator, for storing an execution plan having a time stamp and for retrieving and synchronizing the execution trace record and the execution plan; and

a client process for displaying the retrieved execution trace information to a user after execution of the query.

15 32. The apparatus of claim 31, wherein the data server and the query coordinator stores the execution trace record and the execution plan while executing the query.

20 33. The apparatus of claim 31, wherein the query execution comprises a plurality of execution threads, and the query coordinator synchronizes the execution trace records according to the thread ID and the time stamp.

25 34. The apparatus of claim 31, wherein the time stamp is an absolute time stamp.

35. The apparatus of claim 31, wherein the time stamp is a logical time stamp.

ABSTRACT OF THE DISCLOSURE

A method, apparatus, article of manufacture, and a memory structure for monitoring an executed query comprising at least one execution thread is disclosed. The method comprises the steps of executing the query; and while executing the

5 query, storing an execution trace record for each execution thread in at least one execution log file. The execution trace record comprises execution trace information including a thread ID and a time stamp for the execution thread. The execution trace information can be recalled from the execution log file and presented to a user after execution of the query to allow post mortem analysis of the query. The article of

10 manufacture comprises a program storage device tangibly embodying instructions for performing the method steps described above. The apparatus comprises a data server for executing the execution thread and for storing an execution trace record for the executed execution thread, the execution trace record having execution trace information including a thread identifier and a time stamp; a query coordinator, for

15 storing an execution plan having a time stamp and for retrieving and synchronizing the execution trace record and the execution plan; and a client process for displaying the retrieved execution trace information to a user after execution of the query.

"Express Mail" mailing label number EL301994043445
Date of Deposit NOVEMBER 24, 1997
I hereby certify that this paper or fee is being de-
livered with the United States Postal Service "Express
Office to Addressee" service under 37 CFR 1.10(e)
to Isabell Ogata indicated above and is addressed to:
A. Commissioner for Patents, Washington, D.C. 20231.

Isabell Ogata
(printed name)

Isabell Ogata
(Signature)

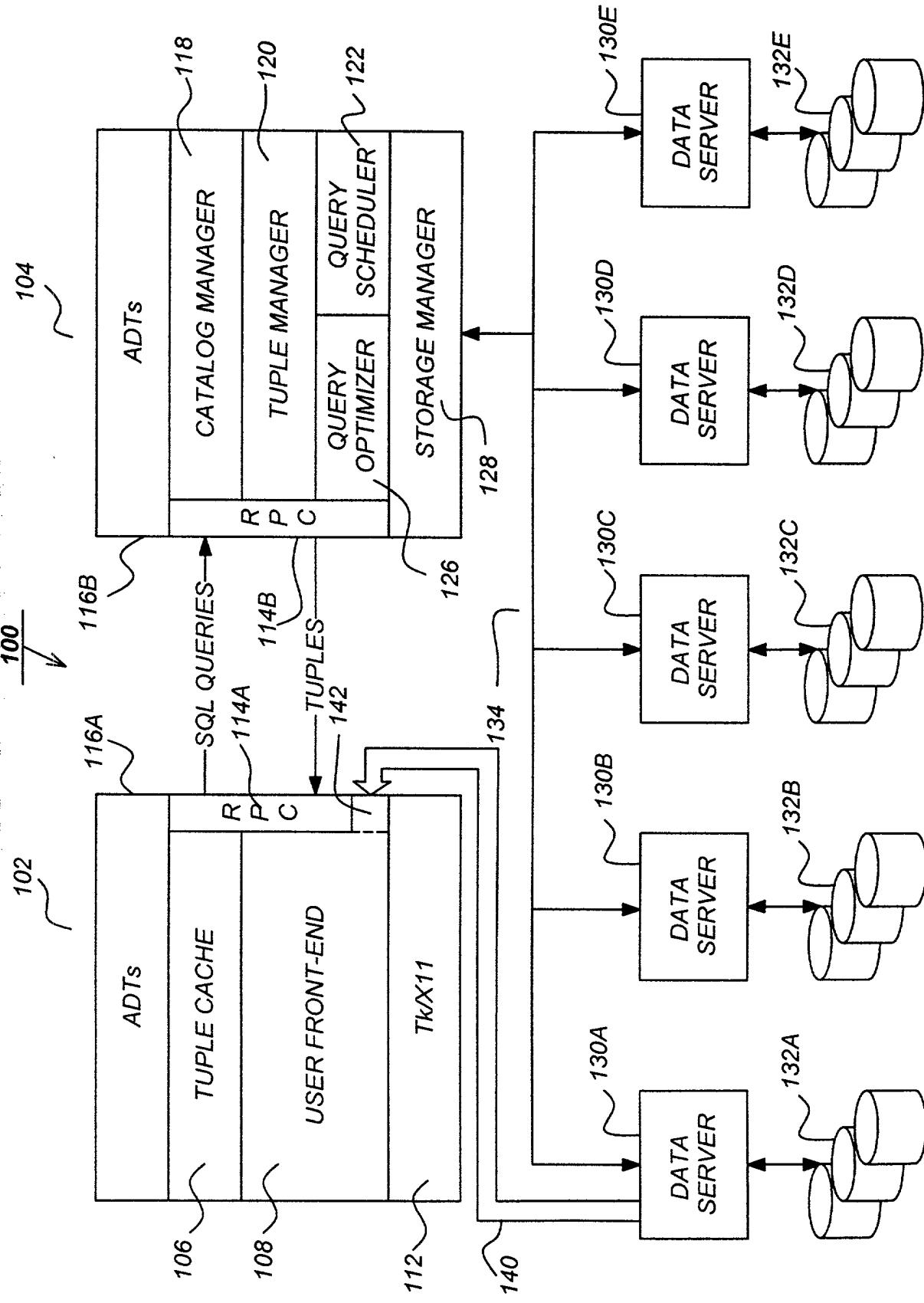


FIG. 1

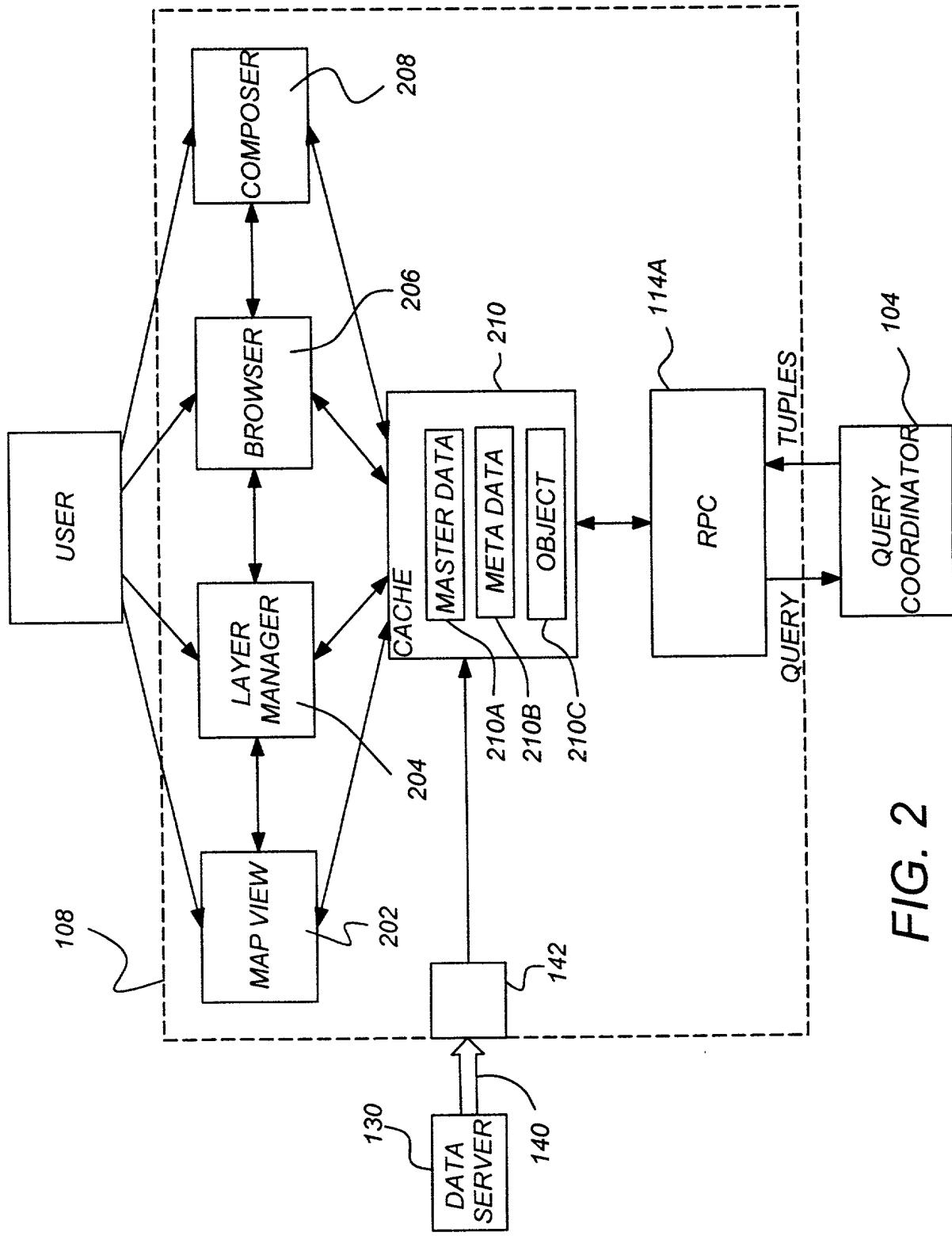


FIG. 2

FIG. 3A

```
SELECT * from Emp,Dept
where Emp.dno = Dept.dno
and Emp.name = "Lee"
```

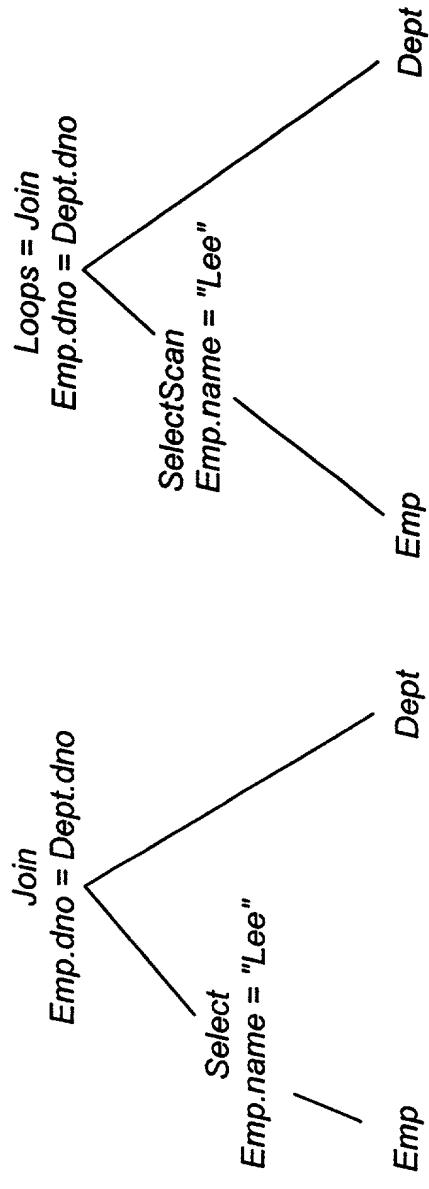


FIG. 3A

FIG. 3B

FIG. 3C

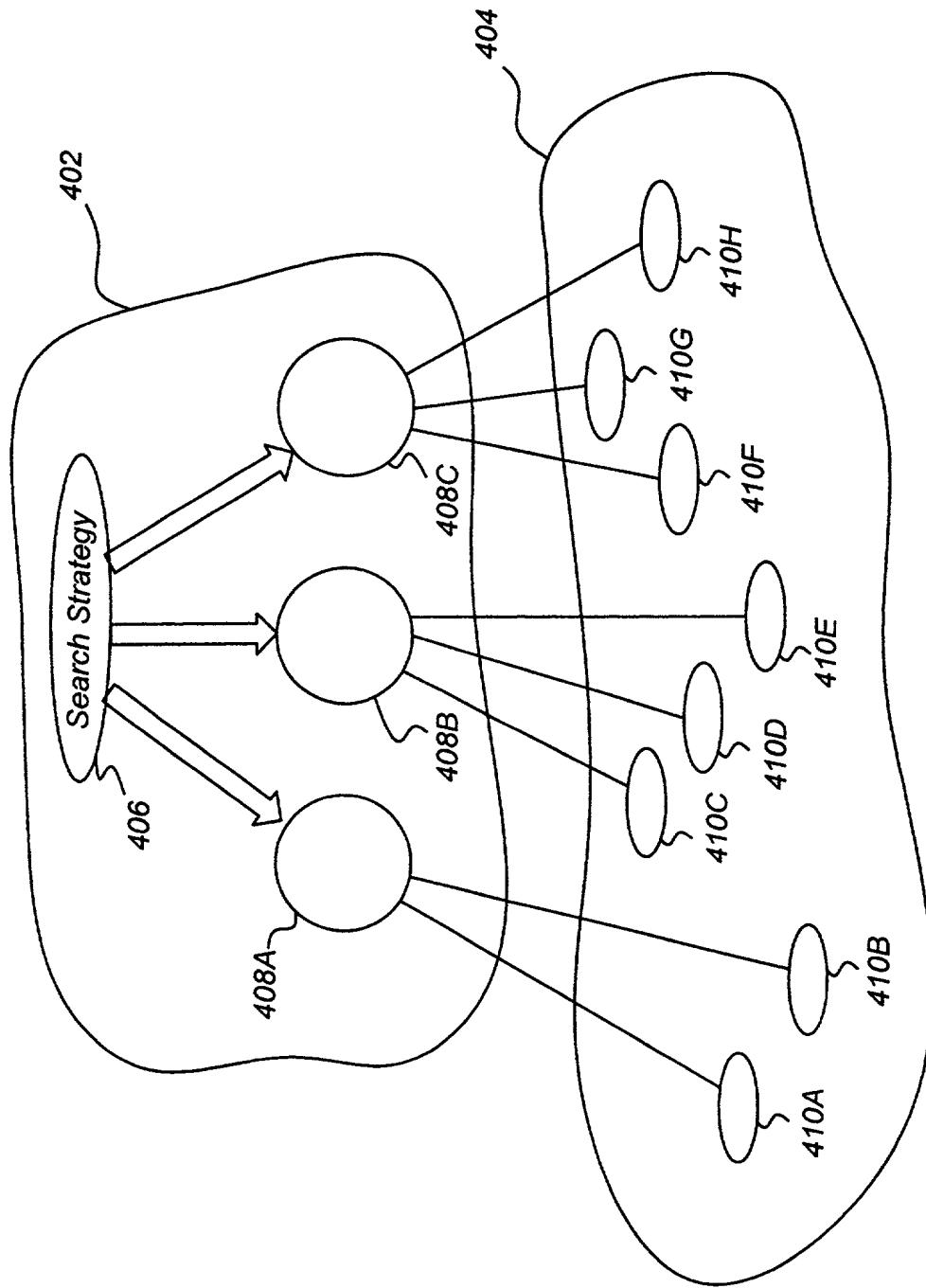


FIG. 4

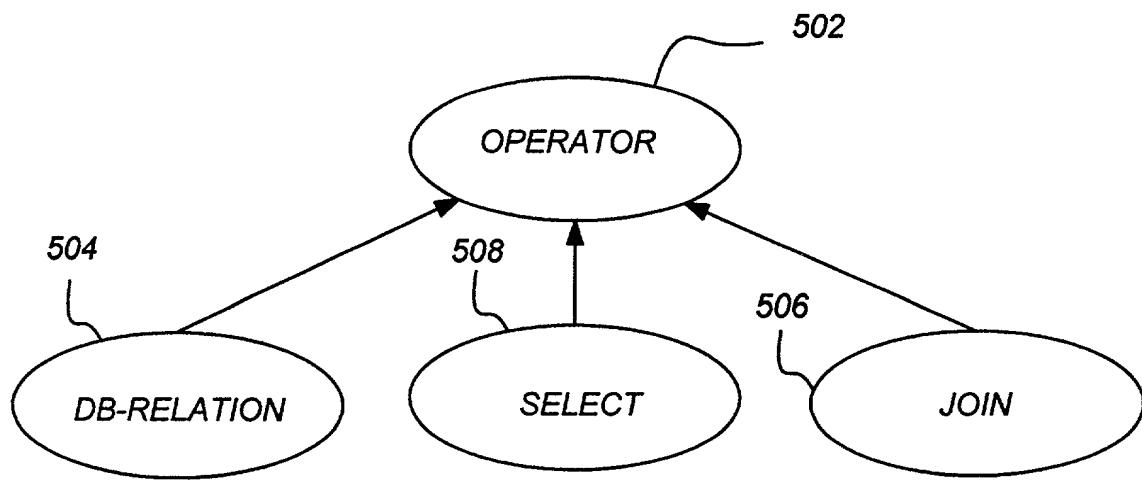


FIG. 5

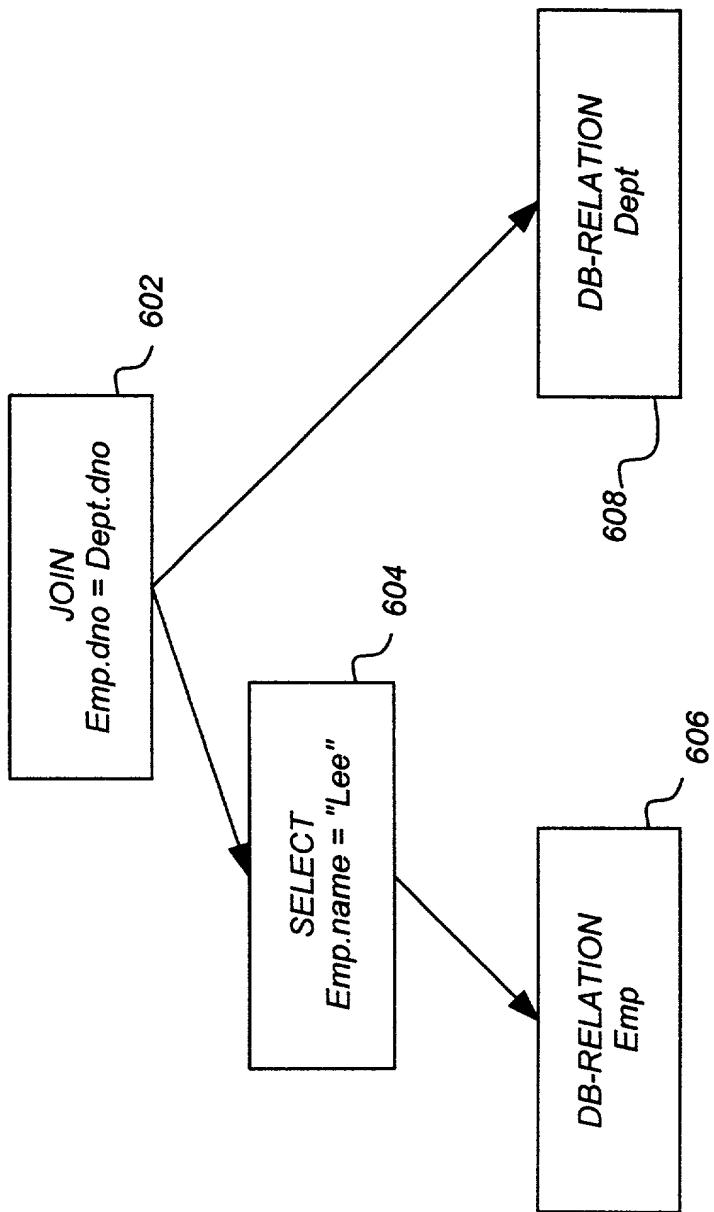


FIG. 6

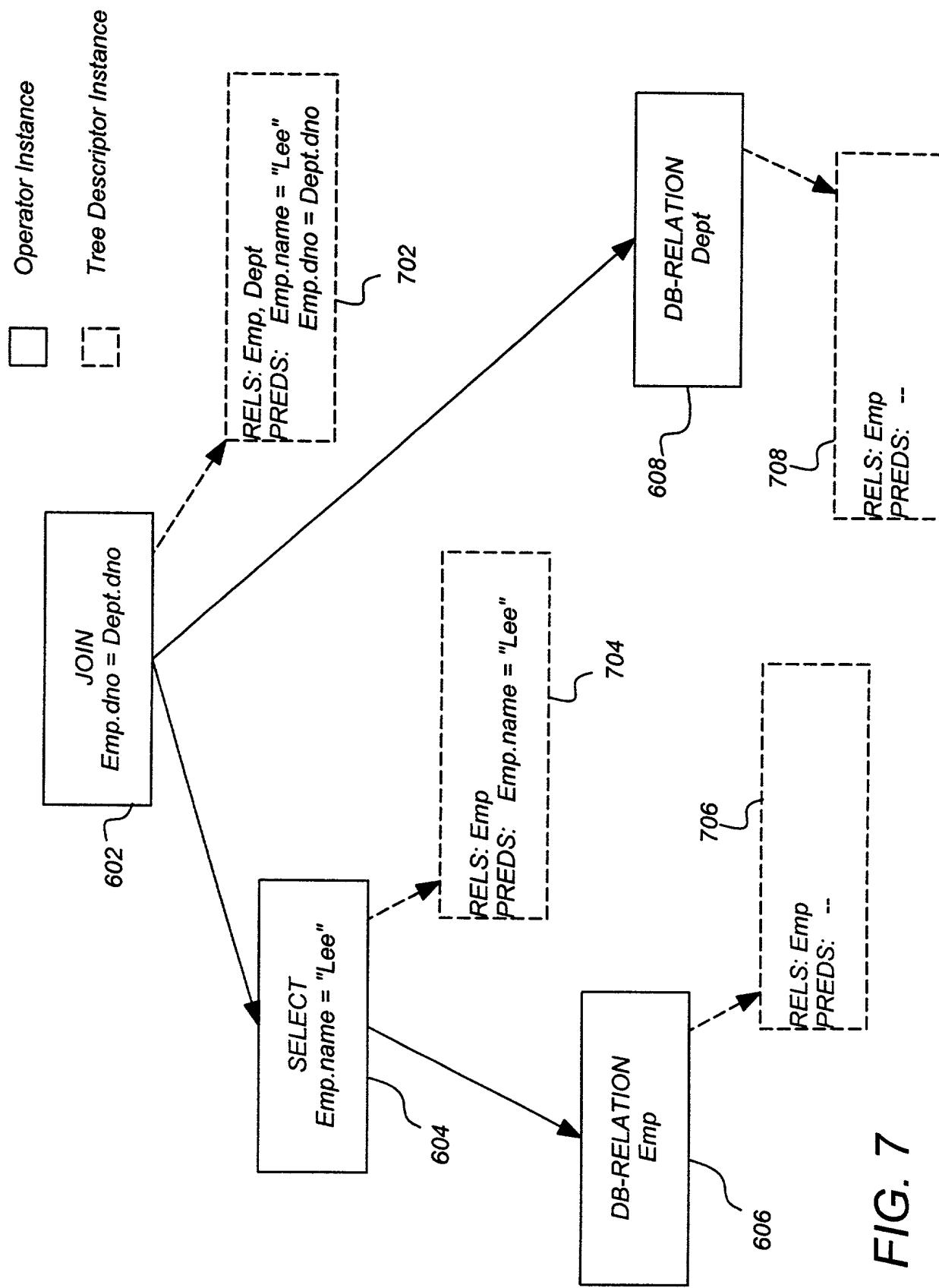


FIG. 7

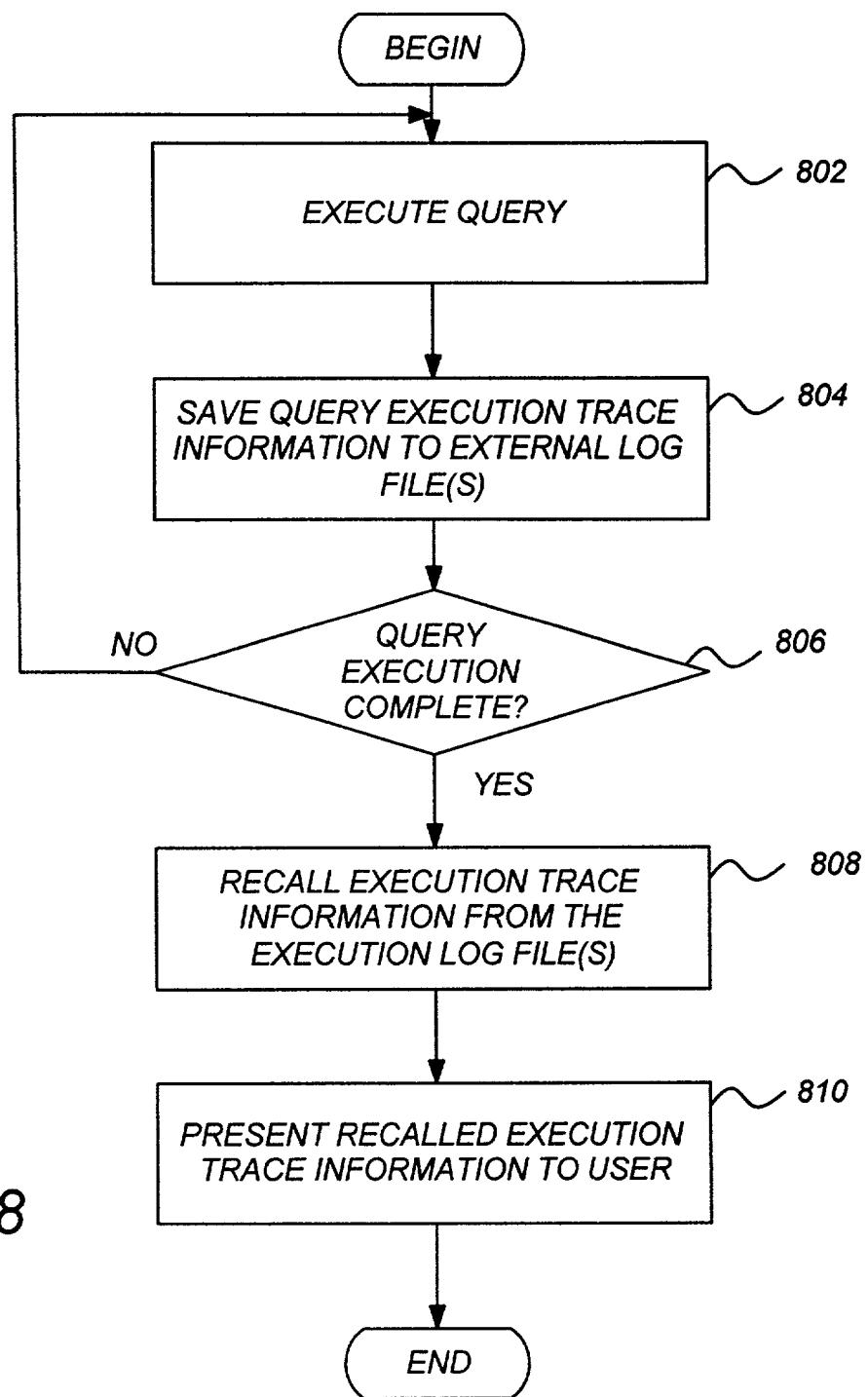


FIG. 8

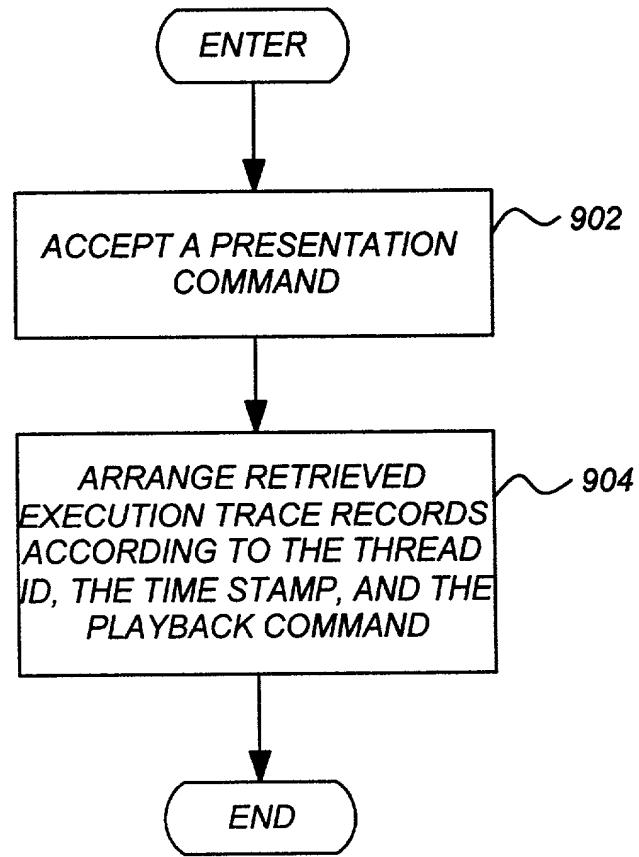


FIG. 9

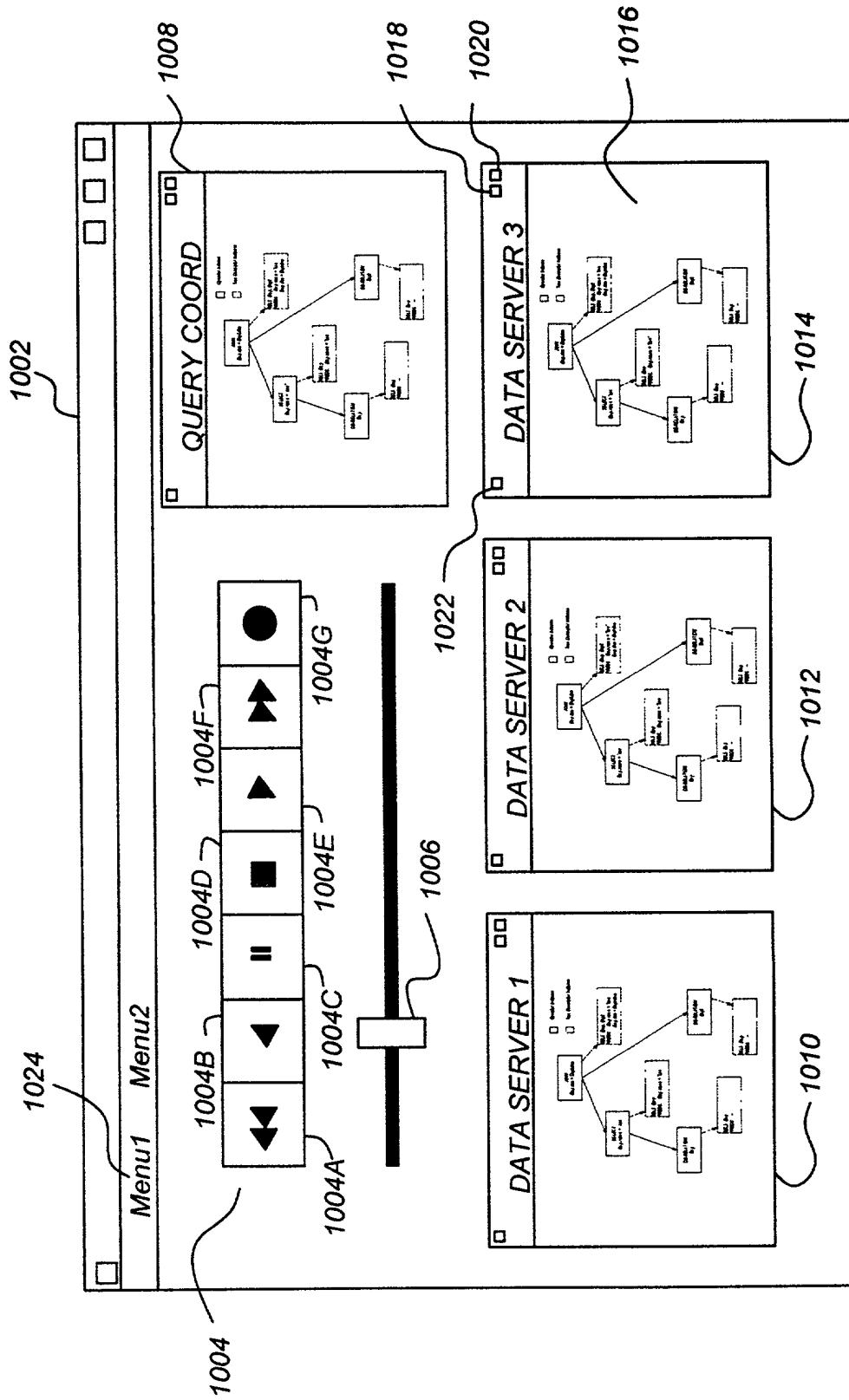


FIG. 10

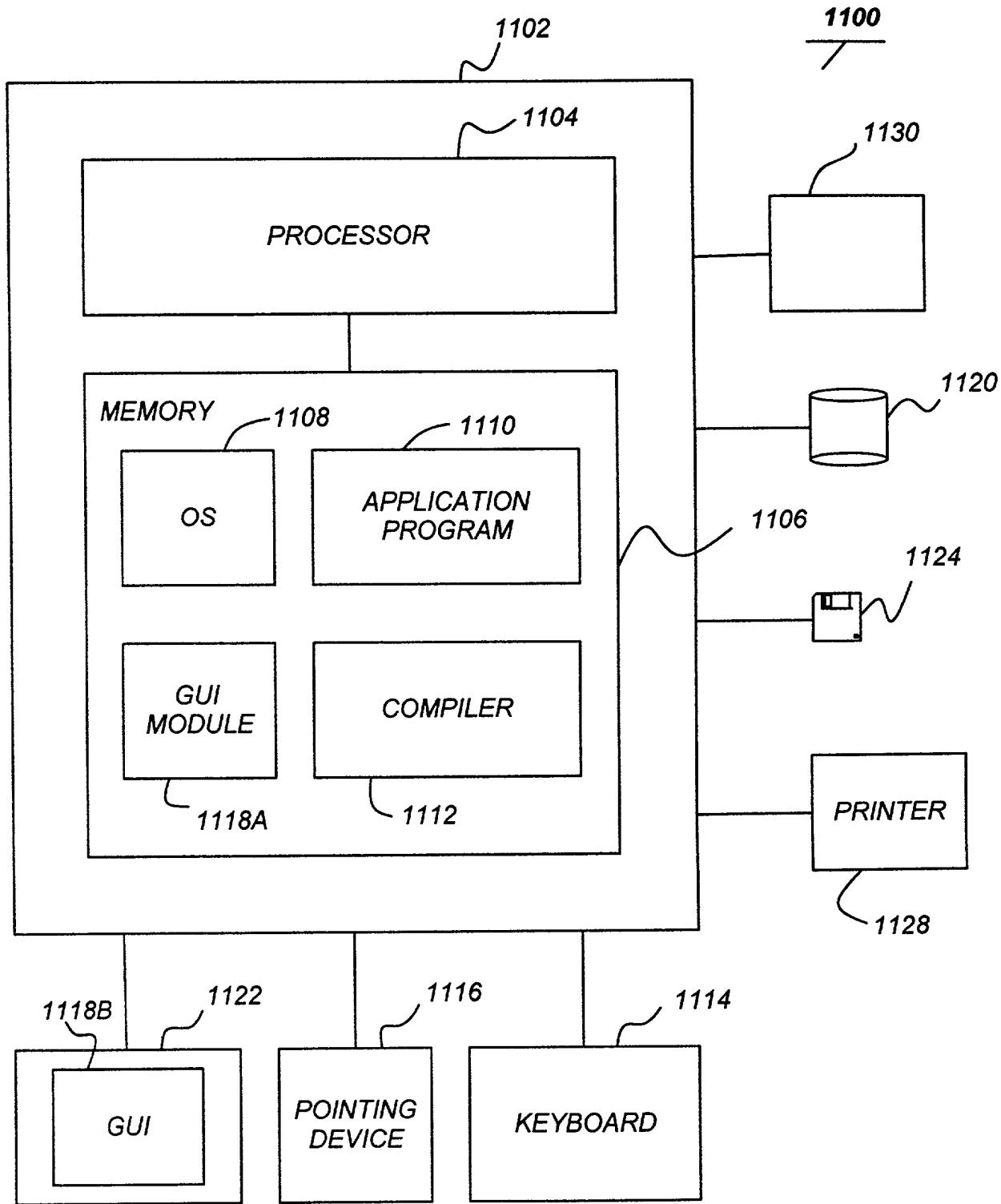


FIG. 11

DECLARATION AND POWER OF ATTORNEY

As a below named inventor, I hereby declare that:

my residence, post office address and citizenship are as stated below next to my name;

I verily believe I am the original, first and sole inventor (if only one name is listed below) or an original, first and joint inventor (if plural names are listed below) of the subject matter which is claimed and for which a patent is sought on the invention entitled:

QUERY MONITOR PLAYBACK MECHANISM FOR POST-MORTEM PERFORMANCE ANALYSIS (Docket No. 8343), the specification of which

is attached hereto.

was filed on _____ as Application Serial No. _____
and was amended on _____
(if applicable)

I hereby state that I have reviewed and understand the contents of the above-identified specification, including the claims, as amended by any amendment referred to above.

I acknowledge the duty to disclose information which is material to the patentability of this application in accordance with Title 37, Code of Federal Regulations, § 1.56(a).

I hereby claim foreign priority benefits under Title 35, United States Code, § 119 of any foreign application(s) for patent or inventor's certificate listed below and have also identified below any foreign application for patent or inventor's certificate or any PCT application having a filing date before that of the application on the basis of which priority is claimed: **None**

Prior Foreign Application(s)	Priority Claimed			
(Number)	(Country)	(Day/Month/Year Filed)	Yes	No

I hereby claim the benefit under Title 35, United States Code, § 120 of any United States application(s) listed below and, insofar as the subject matter of each of the claims of this application is not disclosed in the prior United States application in the manner provided by the first paragraph of Title 35, United States Code, § 112, I acknowledge the duty to disclose material information as defined in Title 37, Code of Federal Regulations, § 1.56(a) which occurred between the filing date of the prior application and the national or PCT international filing date of this application: **None**

(Application Serial Number) (Filing Date) (Status) (Patented/Pending/Abandoned)

And I hereby appoint:

Douglas S. Foote of Dayton, Ohio, Registration No. 31,013, James M. Stover of Dayton, Ohio, Registration No. 32,759, and Paul W. Martin of Dayton, Ohio, Registration No. 34,870, all of whom are attorneys with NCR Corporation, 101 W. Schantz Avenue, Dayton, Ohio 45479; and

George H. Gates of Los Angeles, California, Registration No. 33,500, Victor G. Cooper of Los Angeles, California, Registration No. 39,641, Anthony J. Orler of Los Angeles, California, Registration No. 41,232, Karen S. Canady of Los Angeles, California, Registration No. 39,927, William J. Wood of Los Angeles, California, Registration No. 42,236, and Jason S. Feldmar of Los Angeles, California, Registration No. 39,187, all of whom are attorneys with the law firm of Gates & Cooper, 6701 Center Drive West, Suite 1050, Los Angeles, California 90045;

as my attorneys with full power of substitution and revocation, to prosecute this application and to transact all business in the Patent and Trademark Office connected therewith. I hereby expressly waive my right to revoke the Power of Attorney granted above.

Address all telephone calls to James M. Stover at telephone number 937/445-7663. Address all correspondence to James M. Stover, NCR Corporation, 101 W. Schantz Avenue, ECD-2, Dayton, Ohio 45479.

I hereby declare that all statements made herein of my own knowledge are true and that all statements made on information and belief are believed to be true; and further that these statements were made with the knowledge that willful false statements and the like so made are punishable by fine or imprisonment, or both, under § 1001 of Title 18 of the United States Code and that such willful false statements may jeopardize the validity of the application or any patent issued thereon.

Full name of first inventor: Karthikeyan (NMI) Ramasamy

Inventor's signature: _____ Date: _____

Residence: 12 Sayner Court #66, Madison, Wisconsin 53717

Citizenship: India

Post Office Address: Same as above

Full name of second inventor: Jie-Bing (NMI) Yu

Inventor's signature: _____ Date: _____

Residence: 6765 Mallee Street, Carlsbad, California 92009

Citizenship: People's Republic of China

Post Office Address: Same as above

Full name of third inventor: Jun (NMI) Li

Inventor's signature: _____ Date: _____

Residence:

Citizenship:

Post Office Address:

2025 RELEASE UNDER E.O. 14176